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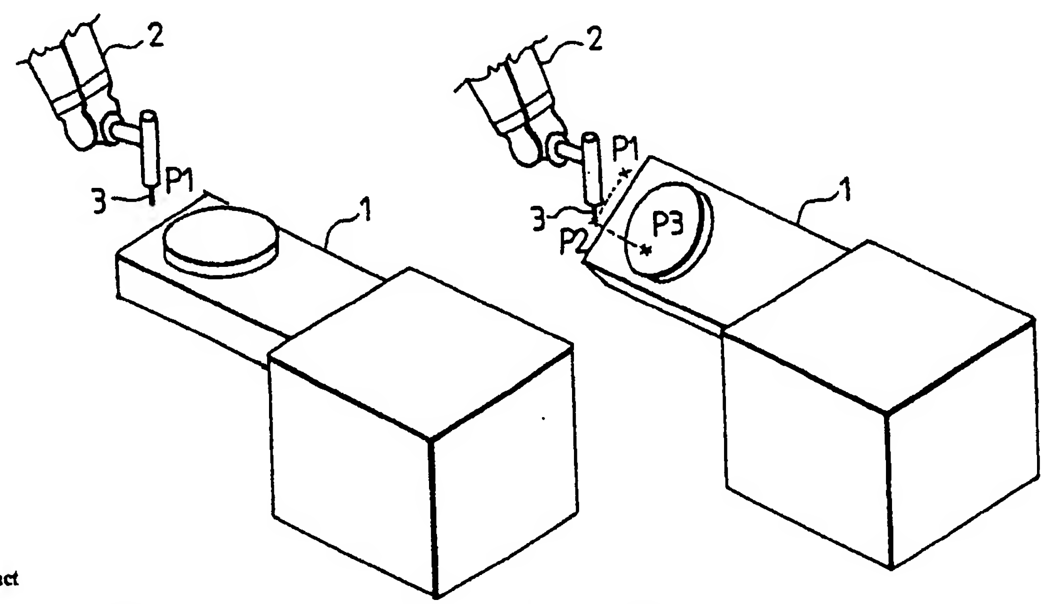

(57) Abstract

The invention relates to a method of controlling the movements of a robot and a workpiece manipulator during the teaching of the robot cell. To achieve synchronized teaching of the robot cell the method comprises driving one cell component, that is, the robot (2) or the workpiece manipulator (1), to a position required by the following point (P3) to be taught, the other component following synchronously the moved one so that the position of the robot tool remains unchanged with respect to the workpiece; driving the other cell component, from the position of the point (P1) taught first to the following point (P3), corresponding to the position of the other component, and storing the coordinates of said point in the memory; and repeating said steps to teach all the required points of the paths to be taught.

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Synchronized teaching of a robot cell

This invention relates to a method of controlling the movements of a robot and a workpiece manipulator (rotary table) synchronously during the teaching of the robot cell.

In prior art systems the robot and the rotary table can be operated in synchronization with each other when repeating a taught program path, thus obtaining a controlled path movement with respect to the workpiece positioned on the rotary table. The systems enable complicated paths as compared with systems with no synchronization.

A frequent problem associated with the teaching of this kind of robot system (cell) is that to avoid the risk of collision the robot usually has to be displaced sufficiently far from the rotary table before each moving operation of the manipulator. Thereafter the workpiece is turned into the desired position by means of the rotary table, and the tip point of the tool has to be driven to the required position, which has to be stored in the memory of the control system (cf. U.S. Patent 4,836,742, for instance). This occurs frequently during the teaching, so the teaching is time-consuming as compared with a system which does not comprise a rotary table. Also, the teaching of the points is difficult if there is little room available. A welding robot cell comprising, for instance, a robot of five to six degrees of freedom and a workpiece manipulator (rotary table) of one to two degrees of freedom is a typical example in this respect.

The object of the present invention is to solve problems associated with the control of the movements of the robot and the rotary table during the teaching

of the points. To achieve this, the method of the invention is characterized by the steps of driving one cell component, that is, the robot or the workpiece manipulator, to a position required by the following point to be taught while the other component follows synchronously the one that is moved in such a way that the position of the robot tool with respect to the workpiece remains unchanged; driving the other cell component, that is, the robot of the workpiece manipulator, from the position of the point taught first to the following point, corresponding to the position of the other component, and storing the coordinates of said point in the memory; and repeating the steps c to d until all the required points of the paths to be taught have been taught.

The other preferred embodiments of the invention are characterized by what is disclosed in the attached claims.

In the following the invention will be described in greater detail by means of an example and with reference to the attached drawings, wherein

Figure 1 is a perspective view of a robot cell;

Figure 2 shows a reduced model of the robot cell of Figure 1;

Figure 3 is a block diagram of a robot cell control system; and

Figure 4 shows the operation of the different components of the robot cell during teaching.

The systematic use of the method of the invention requires that the robot cell comprises a robot of at least three degrees of freedom, a rotary table of at least one degree of freedom, and a control unit controlling the robot and the table.

Figure 1 shows one specific system for realizing the synchronized teaching according to the

invention. In this arrangement a workpiece is attached to the rotary table 1 and a required tool to the robot 2, or vice versa. In the following example, the workpiece is attached to the rotary table, and the tool, in this case a welding burner 3, to the tool flange of the robot.

The joints of the robot and the rotary table may be e.g. rotary-type joints or linear joints. In this particular case the robot 2 is a joint mechanism of six degrees of freedom, in which all the joints are rotary joints. The axes of rotation of the joints are indicated J1, J2, J3, J4, J5, J6. The rotary table 2 comprises two rotary joints the axes of which are indicated J7 (turning) and J8 (rotation). As is known from the prior art, each joint comprises a motor which can be operated through a respective joint servo. To read the position of the joint, the motors comprise absolute encoders from which signals are applied to the respective joint servos. These components are known from the prior art and are not shown in Figure 1.

Figure 2 shows a reduced model of the arrangement of Figure 1. The position of the rotary table is represented by a rectangular coordinate system T, a rectangular coordinate system W is positioned in the fastening base of the robot; and a rectangular coordinate system P is positioned at the tip of the tool. The position of the coordinate system T is determined by the joint angles of the axes of the rotary table.

The direction of the coordinate system W of the robot 2 is selected so that the z axis is set in parallel with the joint J1, the y axis in parallel with the joint J2 when the joint angle of J1 is equal to 0, and the x axis is set perpendicular to the

otherd axes. The origin of the coordinate system W is positioned at the intersection B of the axes J1 and J2.

The z axis of the coordinate system of the rotary table 1 points in the direction of the axis J8 (= the direction of J1); and the x axis is set in parallel with the axis J7 and with the x axis of the coordinate system W when the axis J8 is at an angle of 0. The origin of the coordinate system T is at the intersection A of the axes J7 and J8 (cf. Figure 1).

The position and orientation of the coordinate system P of the tool with respect to the coordinate system W depend on the joint angles J1 to J6 of the robot; the origin of the coordinate system of the tool is positioned at the tip point of the tool.

Path teaching according to the invention takes place point by point by first driving the tip point 4 of the tool by means of a manual control to a desired point. Thereafter the operator may change the orientation between the tool and the workpiece by operating the joints of the rotary table in synchronization with the robot. In welding, for instance, it is thus possible to find the right burner angle with respect to the workpiece to be welded without having to displace the robot to a safety distance and back because the orientation of the tool remains constant with respect to the coordinate system W due to the synchronization.

When the rotary table is operated synchronously with the robot, the path calculation is performed with respect to the coordinate system T in place of the coordinate system W. The calculation unit of the control system performs the required transformations from the coordinate system W to the coordinate system T and vice versa. When operating the joints of the

rotary table during the teaching, the control unit keeps the tip point of the tool in a constant position with respect to the workpiece positioned on the rotary table. The orientation of the tool can be kept constant either with respect to the coordinate system T, whereby the tool remains in the same position with respect to the workpiece when operating the joints of the rotary table, or with respect to the coordinate system W, whereby the top of the tool remains in the same position with respect to the workpiece.

During one calculation period the synchronized teaching movements are calculated through the following steps:

- calculating the position Pw of the tool in the coordinate system W on the basis of the joint angles of the robot or utilizing the tool position calculated during the preceding calculation period,
- transforming the point Pw from the coordinate system W to the coordinate system T (point Pt),
- adding to the joint angles of the rotary table the angle of change required by the driving speed,
- calculating the position of the point Pt in the coordinate system W using the new joint angles of the rotary table (point Pw2),
- calculating new joint angles for the robot on the basis of the point Pw2.

The duration of the calculation period is constant, typically some tens of milliseconds.

When performing synchronized teaching movements, the control unit calculates, during each calculation period, the position Pw of the tool in the coordinate system W at this particular moment. The point P can be presented in the form of a transformation matrix

$$P_W = \begin{pmatrix} nx & ox & ax & px \\ ny & oy & ay & py \\ nz & oz & az & pz \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

where vector (px,py,pz) = position of the origin of the point

vector (nx,ny,nz) = the x axis of the coordinate system of the tool at the point P

vector (ox,oy,oz) = the y axis of the coordinate system of the tool at the point P

vector (ax,ay,az) = the z axis of the coordinate system of the tool at the point P

The transformation of the point Pw from the coordinate system W to the coordinate system T takes place by multiplying the point Pw by the inverse matrix T' of the transformation matrix T describing the position and orientation of the coordinate system T

$$Pt = T'*Pw$$

The matrix T is easy to determine when the position of the origin of the coordinate system T in the coordinate system W and the joint angles J7, J8 of the axes of the rotary table are known

$$T = \begin{pmatrix} C8 & -S8 & 0 & px \\ C7*S8 & C7*C8 & -S7 & py \\ S7*S8 & S7*C8 & C7 & pz \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

where C7 = cos(J7)
C8 = cos(J8)
S7 = sin(J7)
S8 = sin(J8)
vector (px,py,pz) = position of the origin of the coordinate system T in the coordinate system W

The transformation of the point Pt back to the coordinate system W is carried out as follows

Pw2 = T*Pt

If the orientation of the tool is to be kept constant with respect to the coordinate system W, the position vector (px,py,pz) of the calculated point Pw2 is used, and when calculating orientation vectors for the point Pw, the joint angles J1 to J6 of the robot are used. If the orientation of the tool is to be kept constant with respect to the coordinate system T, the joint angles J1 to J6 of the robot can be calculated directly from the point Pw2.

Figure 3 shows the robot cell control system by means of which the robot and the rotary table can be operated simultaneously. It is formed by a calculation unit 5 and its program storage 6 which together form a data processing unit 4 indicated with broken lines; a manual control panel 7; and joint servos 8 connected to respective motors 9 and encoders 10 for the robot and the rotary table. Each joint servo 8 controls its joint J1 to J8 in response to instructions received from the calculation unit 5. The calculation unit may, for instance, instruct a determined joint servo 8 to drive up to a desired encoder reading.

Figure 4 shows a practical situation. In the

left a welding burner 3 is attached to the arm of the robot 2. An arbitrary workpiece not shown is attached to the rotary table 1 by means of a jig or the like. The point P1 of the workpiece has just been taught to the robot cell by steering the welding burner 3 manually to a suitable position with respect to the rotary table 1. In the right the rotary table 1 has been turned with respect to the axis J7 of Figure 2 over a determined distance for the point to be taught next. Due to the synchronization according to the invention the arm of the robot 2 thereby automatically follows the movement of the rotary table 1 to the point P2, in which the position of the tip of the welding burner 3 is constant with respect to the workpiece (not shown). As mentioned above, the teaching may also be such that the orientation of the tool remains constant with respect to the workpiece. The new point P3 can now be taught to the system by driving the welding burner 3 by means of the robot to a new position, possibly by changing the position of the burner 3, into the point P3 shown in the figure. This is repeated until all the points P1 to Pn required for achieving a desired path are taught.

It is obvious to one skilled in the art that the different embodiments of the invention are not limited to the above examples, but they can vary within the scope of the attached claims.

Claims:

1. A method of controlling the movements of a robot and a workpiece manipulator during the teaching of the robot cell, wherein the robot cell is taught paths required for machining operations to be performed on a workpiece attached to the workpiece manipulator by driving the tool (3) of the robot (2) to the different points of the workpiece to be taught and by storing the coordinates of the points in a memory, the method comprising the steps of:

a) driving the tool (3) of the robot to a work-piece point (P1) to be machined first;

b) storing the coordinates of the first work-piece point in the memory (6) of the control system of the robot cell;

c h a r a c t e r i z e d by the steps of

c) driving one cell component, that is, the robot (2) or the workpiece manipulator (1), to a position required by the following point (P3) to be taught while the other component follows synchronously the one that is moved in such a way that the position of the robot tool with respect to the workpiece remains unchanged;

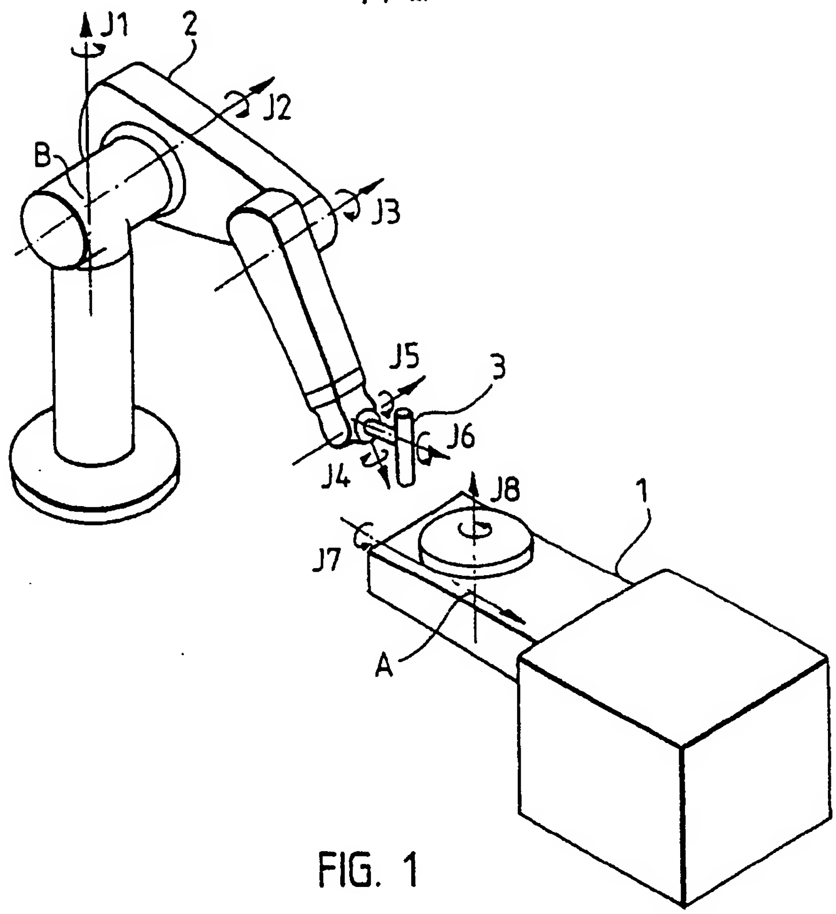
d) driving the other cell component, that is, the robot (2) of the workpiece manipulator (1), from the position of the point (P1) taught first to the following point (P3), corresponding to the position of the other component, and storing the coordinates of said point in the memory; and

e) repeating the steps c to d until all the required points of the paths to be taught have been taught.

2. A method according to claim 1, c h a r a c t e r i z e d in that mainly the workpiece

manipulator (1) is controlled during the teaching so as to turn the workpiece to a suitable position for the point to be taught next, and that mainly the robot (2) is synchronized with the movements of the workpiece manipulator during the teaching.

3. A method according to claim 1, c h a r a c t e r i z e d in that mainly the robot (2) and its tool (3) are controlled during the teaching so that they point the coordinates of the point to be taught next, and that mainly the workpiece manipulator (1) is synchronized with the movements of the robot during the teaching.


J1
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J2
B
J3
J5
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J6
J4
J8
1
J7
A

FIG. 1

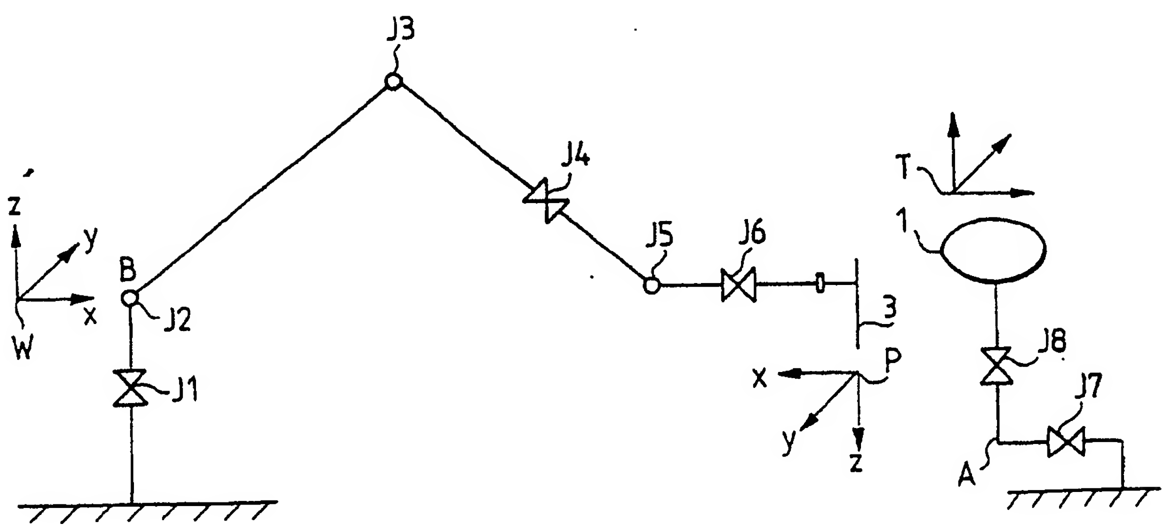
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FIG. 2

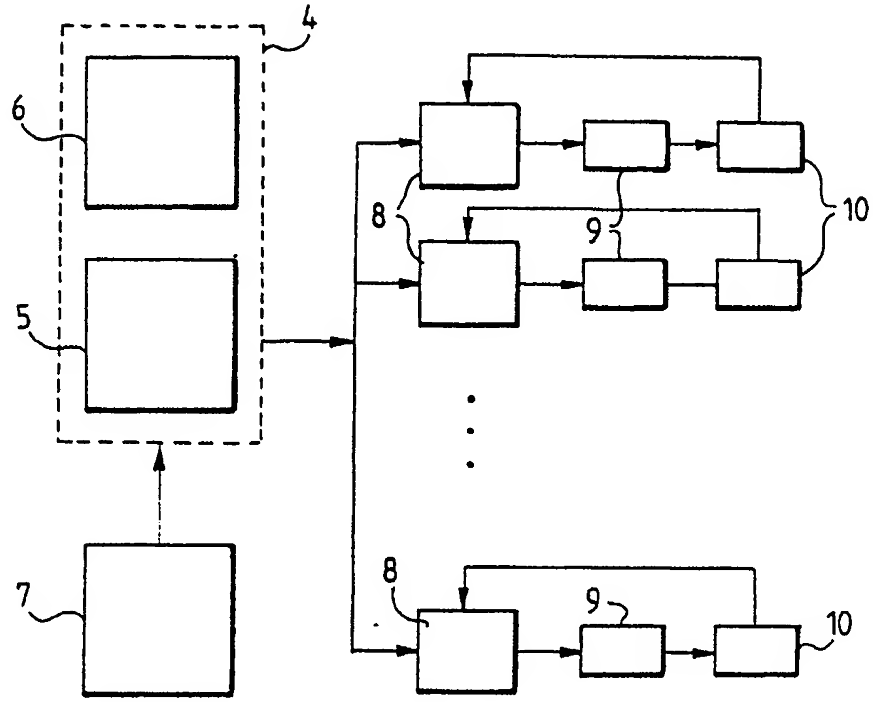

FIG. 3

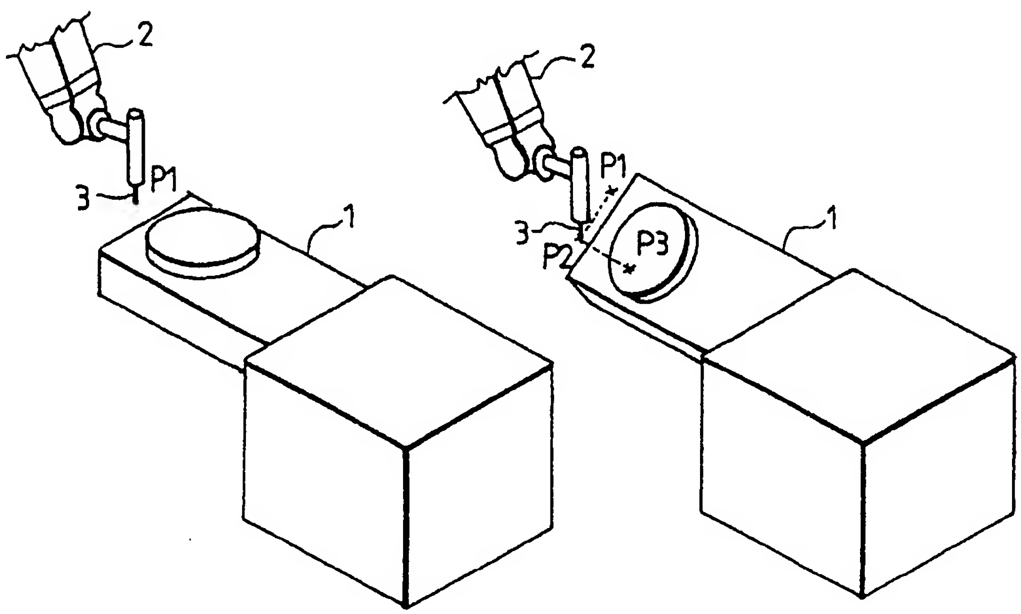

FIG. 4

INTERNATIONAL SEARCH REPORT

International Application No PCT/FI 90/00192

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all)[6]

According to International Patent Classification (IPC) or to both National Classification and IPC

IPC5: G 05 B 19/417, B 25 J 9/16

II. FIELDS SEARCHED

Minimum Documentation Searched[7]

Classification System	Classification Symbols
IPC5	G 05 B, B 25 J

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in Fields Searched[8]

SE,DK,FI,NO classes as above

III. DOCUMENTS CONSIDERED TO BE RELEVANT[9]

Category *	Citation of Document,[11] with indication, where appropriate, of the relevant passages [12]	Relevant to Claim No.[13]
A	WO, A, 8905486 (FANUL) 15 June 1989, see abstract --	1-3
A	EP, A, 177142 (CINCINNATI MILACRON) 9 April 1986, see abstract --	1-3
A	EP, A, 271691 (SIEMENS) 22 June 1988, see abstract --	1-3
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IV. CERTIFICATION

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ANNEX TO THE INTERNATIONAL SEARCH REPORT ON INTERNATIONAL PATENT APPLICATION NO.PCT/FI 90/00192

This annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report.
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Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO-A- 8905486	89-06-15	JP-A- 1149113	89-06-12
EP-A- 177142	86-04-09	NONE	
EP-A- 271691	88-06-22	NONE	
US-A- 4836742	89-06-06	EP-A-B- 0158447 JP-A- 60193016	85-10-16 85-10-01